DOCUMENT RESUME

ED 244 805 SE 044 530

AUTHOR Walkosz, Margaret; Yeany, Russell H.
TITLE Effects of Lab Instruction Emphasizing Process Skills on Achievement of College Students Having Different Cognitive Development Levels.
PUB DATE 84
NOTE 28p.; Paper presented at the Annual Meeting of the National Association for Research in Science Teaching (57th, New Orleans, LA, April, 1984).
PUB TYPE Reports - Research/Technical (143) -- Speeches/Conference Papers (150)

EDRS PRICE MF01/PC02 Plus Postage.
DESCRIPTORS *Academic Achievement; Biology; *Cognitive Development; *College Science; Higher Education; *Process Education; Science Education; *Science Instruction; Sex Differences; *Skill Development; Student Attitudes
IDENTIFIERS Science Education Research; Test of Logical Thinking (Tobin and Capie)

ABSTRACT

This study compared the process skill achievement of students (N=107) completing traditional laboratory exercises with students (N=127) not only completing the same exercises but also receiving instruction in such integrated process skills as identifying variables and stating hypotheses. The relationships among process skill achievement, cognitive development, overall course achievement, sex, and attitudes were also examined. Results indicate that emphasis on process skills in the laboratory can significantly improve process skill achievement. Students with lower levels of cognitive development had a lower level of process skill achievement, but there was no difference in gain in process skill achievement across levels of cognitive development. Females on the average had a slightly lower level of cognitive development than males, but there was no sex difference in process skill achievement overall. However, statistical interactions indicated that females at the lowest level of cognitive development scored higher on some of the process skill measures than did males at the same level of cognitive development. In general, this study indicates that, along with gains in content achievement, process skill achievement can be improved in students at all levels of cognitive development through reasonable modifications of existing laboratory exercises. (Author/JN)

****
* Reproductions supplied by EDRS are the best that can be made *
* from the original document. *
****

ED244805

U.S. DEPARTMENT OF EDUCATION
NATIONAL INSTITUTE OF EDUCATION
EDUCATIONAL RESOURCES INFORMATION CENTER (ERIC)
✓ This document has been reproduced as received from the person or organization originating it.
☐ Minor changes have been made to improve reproduction quality.
• Points of view or opinions stated in this document do not necessarily represent official NIE position or policy.

EFFECTS OF LAB INSTRUCTION EMPHASIZING PROCESS SKILLS ON ACHIEVEMENT OF COLLEGE STUDENTS HAVING DIFFERENT COGNITIVE DEVELOPMENT LEVELS

Margaret Walkosz
Division of Biological Sciences
University of Georgia

Russell H. Yeany
Science Education Research & Evaluation Lab
Department of Science Education
University of Georgia

"PERMISSION TO REPRODUCE THIS MATERIAL HAS BEEN GRANTED BY
Russell H. Yeany
TO THE EDUCATIONAL RESOURCES INFORMATION CENTER (ERIC)."

A research paper presented at the annual meeting of the National Association for Research in Science Teaching.

New Orleans
April, 1984

SE044530

EFFECTS OF LAB INSTRUCTION EMPHASIZING PROCESS SKILLS ON ACHIEVEMENT OF COLLEGE STUDENTS HAVING DIFFERENT COGNITIVE DEVELOPMENT LEVELS

INTRODUCTION

For some time, science educators have advocated that, along with science content, students be given an understanding of the "process of science" (AAAS, 1965; Livermore, 1964; Sears & Kessen, 1964). However, studies reveal that incorporation of science processes into science curriculum is still seen on a limited bases (Tobin & Capie, 1980; Yager, 1982). As a result students at all levels of education are found to be lacking in science process skills (Jaus, 1975; Kyle, Penick, & Shymansky, 1979). Several studies have reported success in improving process skill achievement in college-level students through various methods of specific instruction in the skills (Gabel & Rubba, 1980; Gable, Rubba, & Franz, 1977; Jaus, 1975; Pohlmann & Pappelis, 1977, Pappelis, Pohlmann & Pappelis, 1980; Riley, 1979). The investigative-style lab has been suggested as a means of engaging college students in the process of science (Holt, Abramoff, Wilcox, & Abell, 1969); though some studies indicate that this could be an effective approach (Leonard, 1982; Moll & Allen, 1982), a more structured approach may be more effective for some students (Spears & Zollman, 1977), and may be easier to incorporate into a typical college laboratory setting. A set of objectives can provide a framework for incorporating process skills into the science laboratory (Dillashaw & Okey, 1980; Tobin & Capie, 1980). The present study suggests a method of

incorporating process skills into existing lab exercises in introductory college biology based on a set of process skill objectives. (See Figure 1). The results should indicate whether this can be an effective approach for improving process skill achievement in college students.

A factor that may have a strong relationship to process skill achievement is cognitive development. Though theoretically college-age students should have achieved the highest level of cognitive development (a level described as "formal operational", characterized by being able to reason on hypotheses and understand abstract concepts) (Inhelder & Piaget, 1958), many studies reveal that a significant percentage of college students are not formal-level thinkers (Chiappetta, 1976; McKinnon & Renner, 1971; Sanders, 1978; Tobin & Capie, 1981). A relationship between cognitive development and process skill achievement is suggested by the nature of the integrated process skills (e.g., formulating hypotheses) (Good 1977; Green, 1978; Wood, 1974) and is indicated by studies showing a strong correlation between measures of cognitive development and integrated process skills (Lawson, 1980; Lawson, Norland, & Devito, 1975; Marek, 1981; Padilla, Okey & Dillashaw, 1983; Roadrangka, Yeany & Padilla, 1983; Tobin & Capie, 1979, 1981). This study examined the relationships between process skill achievement and cognitive development when process skills are incorporated into the laboratory.

Another variable that may have a relationship to process skill achievement, and also to cognitive development, is gender. Some studies have reported that males outperform females in understanding physical concepts (Howe & Shayer, 1981; Kelly &

Kelly, 1978; Treagust, 1980), in math and science (Keeves, 1973), in recognition of science concept definitions (Lynch & Patterson, 1980), and in cognitive development (Schwebel, 1975). On the other hand, Doran & Sellers (1978) found no relationship between gender and process skill achievement. Yeany, Helseth, & Barstow (1980) reported that when gender was a predictor of introductory college science achievement, females outscored males. In summarizing research in science education for 1979, Butts (1981) noted that boys and girls probably achieve about the same in science at the college level. Since the questions of gender differences seems to be an open one, relationships among gender, process skill achievement, cognitive development and overall achievement in introductory college biology were again be examined in this study.

Though three previous studies involving process skills in which attitude was measured noted no change in attitude toward science as a result of process skill instruction (Gabel, Rubba, & Franz, 1977; Jaus, 1975; Kiley, 1979), the influence of the experimental treatment (emphasis of the integrated process skills in lab) on the attitude of students toward the lab experience was also be considered in this study.

PURPOSE

Many laboratory exercises in introductory college biology require integrated science process skills, but casual observation indicates that many students lack these skills. Therefore, if students are to gain an understanding of the process of science, a

need for more specific instruction in the science process skills is indicated.

One factor to be considered in conjunction with process skills is the cognitive development levels of the students. To teach effectively, instructors needs to do more than outline what they want students to know or be able to do; they also need an understanding of the students' abilities to understand the concepts and ideas being presented. The integrated process skills require a level of sophistication in intellectual (cognitive) development beyond that required for the basic process skills. Therefore, having some measure of the cognitive development of the students might make it possible to teach process skills more effectively.

Another factor to be considered in relation to both process skills and cognitive development is gender. Roles in human society have long been defined by gender. Only in recent history have women sought to achieve the goals and careers long assigned mostly to men. In the past the assumption that men and women had different intellectual capacities went essentially unquestioned; but, educators today should have a real concern for gender differences in aptitude and achievement (whether innate or induced) when and where they truly exist. This could offer another insight into the instructional needs of students.

The purpose of this study was to determine the effect of specific emphasis of the integrated science process skills within a college biology laboratory on students' process skill achievement. The relationships among process skill achievement,

cognitive development, gender, and overall achievement in the course were also determined.

RESEARCH QUESTIONS

The first questions served to compare students in this study to studies cited in the literature review.

1. What is the level of process skill achievement of students in introductory college biology?
2. What is the level of cognitive development of students in introductory college biology?
3. Is there a relationship between process skill achievement and cognitive development?
4. Are there gender differences in process skill achievement and cognitive development?

The following research questions determined the effect of the experimental treatment.

5. Does an introductory college biology course with no specific reference to the integrated science process skills improve process skill achievement?
6. Does a laboratory experience in which the integrated science process skills are emphasized improve process skill achievement?
7. Does the experimental treatment reduce the correlation between cognitive development and process skill achievement?
8. Does level of cognitive development influence improvement in process skill achievement?
9. Are changes due to experimental treatment consistent across levels of cognitive achievement?
10. Are there any gender difference in response to experimental treatment?
11. Is there a relationship between cognitive development and overall achievement in an introductory college biology course?

12. Is there a relationship between process skill achievement and overall achievement in an introductory college biology course?

13. Are there gender differences in overall achievement?

14. Are the attitudes and perceptions of the students about the laboratory changed by the experimental treatment?

METHODS AND DATA SOURCES

Sample and Context

Students (n = 234) enrolled in Biology 102 during Spring and Summer 1982 served as subjects for the study. Two groups of students were selected: a comparison group (n = 107) to determine the effect of the traditional lab exercises on process skill achievement (i.e., "base-line" data) and an experimental treatment group (n = 127) to determine the effect of emphasis of the integrated process skills in the lab.

Students attended lecture four days per week for 50-60 minutes and one three-hour lab per week. The course lecturer was a faculty member while labs were taught by teaching assistants. The lab sequence was composed of 7 lab exercises. Three of the lab exercises (Muscle Physiology, Respiration and Photosynthesis) were used in this study because they lended themselves to process skill emphasis.

Independent Variables

Three independent variables were involved in this study:

(1) Cognitive Development as measured by the Test of Logical Thinking (TOLT) (Tobin and Capie, 1981). Students were classified in five levels based on their score on this 10-item test: level 1 = concrete or non-formal; level 2 = transitional, also non-formal; level 3 = low formal; level 4 = high formal; and level 5 = fully formal.

(2) Gender -- male or female.

(3) Group as defined by treatment. The comparison group was tested, but not given any special instruction in the integrated process skills. The experimental group was listed and given special instruction in the integrated process skills.

The traditional lab exercise of the comparison group included little more than a description of procedures for the lab exercise and tables for recording data. In these exercises, students were not expected to identify variables, state hypotheses, interpret and predict from results, or design experiments; these exercises emphasized data collection and display only.

In the modified lab for the experimental group all of these process skills were included (based on a set of process skill objectives - see Figure 1). Students were required to identify the variables being measured in the experiment, suggest an hypothesis to be tested, identify methods of measurement, etc. The same procedures found in the traditional exercises were followed, but after data are collected and displayed, students were also required to describe, interpret, and predict from the results. At the end of each lab report students were required to choose other variables on the same topic and briefly design an experiment.

Dependent Variables

The dependent variables in this study were measures of achievement and attitude:

(1) Process skill achievement was measured several ways:
   (a) content-specific quizzes (reliability > .73 based on the Spearman-Brown Prophecy formula) which were administered during the lab period following each lab exercise. Achievement was indicated by a raw score for each quiz, and a sum of the three quiz scores.

   (b) achievement on the Test of Integrated Process Skills (TIPS). Two equivalent forms (adapted from Dillashaw & Okey, 1980 and Burns, Wise & Okey, 1983) of the test were prepared; one was administered as a pre-test and the other as a post-test. Process skill achievement was measured as the raw scores on the pre- and post-tests; a gain in process skill achievement was determined for each student by subtracting the pre-test score from the post-test score.

(2) Overall achievement in the course was measured as the proportion of total possible points for the course that each student accumulated.

(3) Attitude was measured by a set of statements about the labs rated with a Likert-type scale. The students were also asked to rank the labs on the basis of providing "new insights" and "improved analytical thinking skill." Differences in attitude were determined as a function of group only (not gender or cognitive development).

RESULTS

Process Skills

The mean entry level process skill ability for the study population (as measured by the pre-Test of Integrated Process Skills) was a score of 29.90 out of a possible 40 points (See Table 1). A significant group difference was indicated favoring

the comparison group ($p < .001$). No gender difference were present.

Both groups showed a statistically significant gain in process skill achievement (post-TIPS minus pre-TIPS), but the gain by the experimental group was much greater. (See Table 1). In spite of the lower entry-level process skill ability, the experimental treatment group has a significantly higher mean post-TIPS score. (See Table 1). For each of the lab quizzes and the sum of the quizzes, the experimental group again had a higher mean score than the comparison group. (See Table 1).

Cognitive Development

The mean score of the Test of Logical Thinking for the entire population was 6.05 out of a possible score of 10 (no significant treatment difference was noted. (See Table 2). 31.5% of the students were classified as non-formal, and 68.5% as formal. (See Table 2).

A moderate relationship was indicated between process skills and cognitive development ($r = .44$). (See Table 3). There were significant differences in mean post-TIPS and quiz scores on the basis of cognitive development; in all cases, as cognitive development level increased, the mean score increased. (See Table 4).

The correlation between process skill achievement and cognitive development was not reduced by experimental treatment. Students at all levels of cognitive development were able to gain equally in process skill achievement.

Gender

For all measures of process skill achievement, there were no significant gender differences noted. (See Table 5).

A significant difference in cognitive development was noted; the mean TOLT score for males was 6.68 and for females was 5.56. Overall, 41% of females and 18.3% of males were classified as non-formal. (See Table 6 & 7).

Statistical interactions between gender and cognitive development across levels of process skill achievement indicated that females at the lowest level of cognitive development significantly outscored males at that level of cognitive development on some measures of Process Skill achievement. (See Figure 2).

Overall Achievement

A relationship was indicated between process skill achievement and overall achievement (r = .31). A relationship was also indicated between cognitive development and overall achievement. The general trend was an increase in mean overall achievement as cognitive development level increased. (See Table 8).

No significant difference in overall achievement was noted on the basis of gender. However, a statistical interaction between gender and cognitive development across levels of overall achievement again indicated that females at the lower levels of cognitive development have significantly higher overall achievement than males at the same levels, though males achieved

higher than females at two of the higher levels of cognitive development. (See Figure 3).

Attitude

No differences in attitude were seen between the comparison and experimental groups, either in rating or ranking of the lab exercises. (See Table 9).

DISCUSSION

The most important result of this study is that modification of lab exercises to emphasize the process skills can be effective in improving process skill achievement. Though the experimental treatment group had an entry level process skill ability lower than the comparison group the experimental group had a higher mean score on the post-TIPS, and a considerably greater gain in process skill achievement. The mean scores on the quizzes gave further evidence of the success of the experimental treatment; in all cases, the mean scores of the experimental group were significantly higher than the mean scores of the comparison group.

These results are encouraging because the modifications involved in the experimental treatment were moderate--no new lab exercises were designed, no new equipment required, no significant increase in time was needed--and yet a significant improvement in process skill achievement was noted.

A somewhat unexpected result was that cognitive development did not affect a student's ability to gain in process skill achievement, i.e., there was no significant difference in gain in process skill achievement across levels of cognitive development.

The expected (or hoped-for) result was that students at the lower levels of cognitive development would have a greater gain than students at the higher level of process skill achievement. However, it was also expected that students at the higher levels of cognitive development would have a higher entry level process skill ability than they exhibited, thus not having as much room for improvement. Since all cognitive development levels gained in process skill achievement, one cannot be dissatisfied with these results even though the process skill achievement difference between cognitive development level groups was maintained after treatment.

This study shows a fairly strong relationship between process skill achievement and cognitive development, and also indicates that a much higher percentage of females than males are at a non-formal level of cognitive development, so <u>why</u> is there no significant gender difference in process skill achievement? A statistical interaction between gender and cognitive development across levels of process skill achievement suggests an explanation; females at the lowest level of cognitive development scored significantly higher than males at the lowest level of cognitive development. Some unidentified factor may be allowing females to compensate for the handicap of lacking in cognitive development. Perhaps females at the non-formal level are using a problem-solving approach that is not reflected by the type of problem used to measure cognitive development.

The results of this study suggest that there is a relationship between process skill achievement and overall achievement in introductory college biology. As with the

traditional lab exercises, the lectures (which are content-oriented) and exams assume that the studnets can understand hypotheses, control and manipulate variables, and read and interpret graphs. Therefore, the students who have these skills will have an advantage over students lacking in process skill abilities.

The data also indicate that the experimental treatment group had a mean overall achievement higher than the comparison group. This suggests that overall achievement was improved by instruction in the process skills which should be made an integral part of science instruction.

TABLE 1

PROCESS SKILL ACHIEVEMENT MEAN SCORES FOR COMPARISON AND EXPERIMENTAL GROUPS

Test	MEAN Comparison	MEAN Experimental	F Ratio	p Level
pre-TIPS*	31.34	28.07	16.09	.000
post-TIPS	32.70	34.00	4.95	.027
Gain**	1.45	6.04	28.76	.000
Photosynthesis	9.83	10.42	11.64	.001
Muscle Physiology	10.44	10.87	3.85	.052
Respiration	10.69	11.71	14.55	.000
Sum of Quizzes***	30.90	33.03	20.67	.000

*Test of Integrated Process Skills
**Gain = post-TIPS minus pre-TIPS
***Sum of Photosynthesis, Muscle Physiology, and Respiration Quizzes

TABLE 2

COGNITIVE DEVELOPMENT LEVEL

Level	% Of Students	
1	15.5	31.5% Non-Formal
2	16.0	
3	17.5	
4	27.0	68.5% Formal
5	24.0	

TABLE 3

RELATIONSHIP BETWEEN PROCESS SKILL ACHIEVEMENT AND COGNITIVE DEVELOPMENT

	Pearson Correlation Coefficient (r)	p Level
Between pre-TIPS and TOLT*	.44	.000

*Test of Logical Thinking

TABLE 4

PROCESS SKILL ACHIEVEMENT MEAN SCORES FOR
COGNITIVE DEVELOPMENT LEVEL GROUPS

Test	Cognitive Development Level Group				
	1	2	3	4	5
	(non-formal)		(	formal	)
post-TIPS	28.73	32.62	34.13	34.36	35.37
Gain	(no significant difference $p = .405$)				
Photosynthesis	9.07	10.03	10.14	10.33	10.67
Muscle Physiology	9.33	10.41	10.67	10.92	11.46
Respiration	9.65	10.77	11.19	11.39	12.42
Sum of Quizzes	27.97	31.26	32.00	32.61	34.61

$p = .000$ in all cases except "Gain"

TABLE 5

PROCESS SKILL ACHIEVEMENT MEAN SCORES
FOR MALES AND FEMALES

Test	Male	Female	F Ratio	p Level
pre-TIPS	No		0.62	.434
post-TIPS	Significant		1.30	.256
Gain	Difference		0.02	.905
Photosynthesis	No		0.34	.562
Muscle Physiology	Significant		1.18	.280
Respiration	Difference		0.42	.489
Sum of Quizzes			0.76	.385

TABLE 6

DIFFERENCE IN COGNITIVE DEVELOPMENT ACROSS GENDER

	Male	Female	F Ratio	p Level
Mean Score on Test of Logical Thinking	6.58	5.56	11.17	.001

TABLE 7

COGNITIVE DEVELOPMENT LEVELS AS DISTRIBUTED ACROSS GENDER

Level	% Of Students Male	% Of Students Female	
1	8.0	20.5	Non-Formal: Male = 18.3%
2	10.3	20.5	Female = 41.0%
3	21.8	14.3	
4	29.9	25.0	Formal: Male = 81.7%
5	29.9	19.6	Female = 59%

TABLE 8

Pearson Product-Moment Correlation Coefficients
Across All Variables

	Gender	Pre-TIPS	TOLT	Gain in Process Skills	Post-TIPS	Photosynthesis Quiz	Muscle Physiology Quiz	Respiration Quiz	Sum of Quizzes	Overall Achievement
Gender	----	.021*	.195	.003	-.004	.087	.038	.138	.118	.085
		.780**	.005	.969	.960	.201	.570	.039	.087	.204
Pre-TIPS		----	.441	-.598	.503	.292	.384	.210	.384	.255
			.000	.000	.000	.000	.000	.005	.000	.001
TOLT			----	-.010	.467	.329	.355	.417	.473	.298
				.902	.000	.000	.000	.000	.000	.000
Gain in				----	.392	.002	-.034	.066	.006	.039
					.000	.997	.662	.393	.936	.613
Post-TIPS					----	.339	.392	.306	.429	.309
						.000	.000	.000	.000	.000
Photosynthesis Quiz						----	.488	.492	.797	.388
							.000	.000	.000	.000
Muscle Physiology Quiz							----	.425	.799	.439
								.000	.000	.000
Respiration Quiz								----	.815	.372
									.000	.000
Sum of Quizzes									----	.509
										.000
Overall Achievement										----

* = r value
** = p value

TABLE 9

RATING OF LABS BY COMPARISON AND EXPERIMENTAL GROUPS

Lab Exercise	New Insights		Improved Analytical Thinking	
	Comp.*	Exp.**	Comp.	Exp.
Photosynthesis	7	5	4	4
Muscle Physiology	1	1	1	1
Respiration	4	4	2	2

* out of 7 labs (Comparison group)
** out of 6 labs (Experimental group)

1. Given a responding variable, suggest some manipulated variables that might affect it.

2. Given a responding variable and some specific manipulated variable, suggest some variables that should be controlled.

3. Given a brief description of an investigation, identify the variables that are manipulated, responding, and controlled.

4. Given a responding variable and some specific manipulated variable, suggest a hypothesis to describe the relationship between the variables.

5. Given a brief description of an investigation, state the hypothesis(es) being tested.

6. Given a brief description of an investigation, state how the variables are being measured.

7. Given a table of data showing the effects of a manipulated variable on a responding variable, construct a graph. (This includes labelling axes, plotting points, drawing the best line.)

8. Given a brief description of an investigation and a graph of the results, describe the graph in words (that is, explain in words the effect of the manipulated variable on the responding variable).

9. Given a brief description of an investigation and a graph of the results, interpolate between and/or extrapolate beyond the existing data.

10. Given an hypothesis, design an experiment to test the effect of the manipulated variable on the responding variable.

FIGURE 1: General Integrated Science Process Skill Objectives

REFERENCES

American Association for the Advancement of Science. Science: A Process Approach. Commentary for Teachers. Washington, D. C.: AAAS, 1965.

Butts, D. P. A summary of research in science education - 1979. Searching the science learning context of the undergraduate collegian. Science Education, 1981, 65(4), 398-411.

Chiappetta, E. L. A review of Piagetian studies relevant to science instruction at the secondary and college level. Science Education, 1976, 60(2), 253-261.

Dillashaw, F. G., & Okey, J. R. A test of the integrated science process skills for secondary science students. Science Education, 1980, 64(5), 601-608.

Doran, R. L., & Sellers, B. Relationships between students' self concept in science and their science achievement, mental ability and gender. Journal of Research in Science Teaching, 1978, 15, 527-533.

Gabel, D., & Rubba, P. Science process skills: where should they be taught? School Science and Mathematics, 1980, 80(2), 121-126.

Gabel, D. J., Rubba, P. A., & Franz, J. R. The effects of early teaching and training experience on physics achievement, attitude toward science and science teaching, and process skill proficiency. Science Education, 1977, 61, 503-511.

Good, R. G. How children learn science: Conceptual development and implication for teaching. New York: Macmillan Publishing Co., 1977.

Green, M. R. Learning theory applied to biology education. The American Biology Teacher, 1978, 40(5), 268.

Holt, C. E., Abramoff, P., Wilcox, L. V., & Abell, D. L. Investigative laboratory programs in biology. A position paper of the commission on undergraduate education in the biological sciences. Bioscience, 1969, 19(2), 1104-1107.

Howe, A., & Shayer, M. Sex-related differences on a task of volume and density. Journal of Research in Science Teaching, 1981, 18(2), 169-175.

Inhelder, B., & Piaget, J. The growth of logical thinking from childhood to adolescence. New York: Basic Books, 1958.

Jaus, H. The effects of integrated science process skill instruction on changing teacher achievement and planning practices. Journal of Research in Science Teaching, 1975, 12, 439-447.

Keeves, J. P. Differences between sexes in math and science courses. International Review of Education, 1973, 19, 47-63.

Kelly, G. N., & Kelly, J. T. Basic physical concepts: do college students have them? Journal of College Science Teaching, 1978, 8(1), 29-31.

Kyle, W. C., Penick, J. E., & Shymansky, J. A. Assessing and analyzing the performance of students in college science laboratories. Journal of Research in Science Teaching, 1979, 15(6), 545-551.

Lawson, A. E. Relationships among level of intellectual development, cognitive style, and grades in a college biology course. Science Education, 1980, 64(1), 95-102.

Lawson, A. E., Nordland, F. H., & Devito, A. Relationships of formal reasoning to achievement, aptitudes and attitudes in preservice teachers. Journal of Research in Science Teaching, 1975, 12, 423-431.

Leonard, W. H. A BSCS-style laboratory approach for university general biology. The American Biology Teacher, 1982, 44(9) 520-524.

Lynch, P. P., & Paterson, R. E. An examination of gender differences in respect to pupils' recognition of science concept definitions. Journal of Research in Science Teaching, 1980, 17(4), 307-314.

Marek, E. A. Correlations among cognitive development, intelligence quotient, and achievement of high school biology students. Journal of Research in Science Teaching, 1981, 18(1), 9-14.

McKinnon, J. W., & Renner, J. W. Are colleges concerned with intellectual development? American Journal of Physics, 1971, 39, 1047.

Moll, M., & Allen, R. D. Student and graduate teaching assistant response to investigative laboratories. Journal of College Science Teaching, 1982, 11(4), 219-222.

Padilla, M. J., Okey, J. R., & Dillashaw, F. G. The relationship between science process skill and formal thinking abilities. Journal of Research in Science Teaching, 1983, 20(3), 239-246.

Pappelis, C., Pohlmann, M. M., & Papellis, A. J. Can instruction improve science process skills of premedical and predental students? Journal of Research in Science Teaching, 1980, 17(1), 25-29.

Pohlmann, M. M., & Pappelis, A. J. Improving process skills among college nonscience majors with Science - A Process Approach materials. Journal of College Science Teaching, 1977, 6, 167-169.

Riley, II., J. P. The influence of hands-on science process training on preservice teachers' acquisition of process skills and attitude toward science and science teaching. Journal of Research in Science Teaching, 1979, 16(5), 373-384.

Roadrangka, V., Yeany, R. H., & Padilla, M. J. The construction and validation of group assessment of logical thinking (GALT). A paper presented at the annual meeting of the National Association for Research in Science Teaching, Dallas, April, 1983.

Sanders, S. G. The importance of the Piaget learning theory for the college teacher. Journal of College Science Teaching, 1978, 7(3), 283-287.

Schwebel, M. Formal operations in first-year college students. Journal of Psychology, 1975, 91(1), 133-141.

Sears, P. B., & Kessen, W. Statement of purposes and objectives of science education in school. Journal of Research in Science Teaching, 1964, 2, 3-6.

Spears, J., & Zollman, D. The influence of structured versus unstructured laboratory on students' understanding the process skills. Journal of Research in Science Teaching, 1977, 14, 33-38.

Tobin, K. G., & Capie, W. Teaching process skills in the middle school. School Science and Mathematics, 1980, 80(7), 590-600.

Tobin, K. G., & Capie, W. The development and validation of a group test of logical thinking. Educational and Psychological Measurement, 1981, 41, 413-423.

Tobin, K. G., & Capie, W. The effects of formal reasoning ability, locus of control and student engagement on science process achievement. A paper presented at the University of South Carolina, 1979, Conference in Educational Research.

Treagust, D. F. Gender-related differences of adolescents in spacial representational thought. Journal of Research in Science Teaching, 1980, 17(2), 91-97.

Wood, D. A. The Piaget - process matrix. School Science and Mathematics, 1974, 74, 407-412.

Yager, R. E. The crisis in biology education. The American Biology Teacher, 1982, 44(6), 328.

Yeany, R. H., Helseth, E. A., & Barstow, W. E. Interactive instructional videotapes, scholastic aptitude, cognitive development and locus of control as variables influencing science achievement. A paper presented at the annual meeting of the National Association for Research in Science Teaching, Boston, April, 1980.